Applying Stochastic Storm Transposition in Design of Urban Drainage Systems

Andersen, Christoffer Bang; Wright, Daniel B.; Thorndahl, Søren Liedtke; Simonsen, Preben Dam; Kraglund, Lene Lykke ; Duus, Lene Bassø

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Project: KLIMAKS

Christoffer Bang Andersen[1], Daniel B. Wright[2], Søren Thorndahl[1], Preben Dam Simonsen[3], Lene Lykke Kraglund[3], Lene Bassø Duus[4]

[1]Aalborg University, Denmark; [2]UW-Madison, USA; [3]Niras, Denmark; [4]Aarhus Vand, Denmark

1 Introduction

Design of urban drainage systems is traditionally based on either Intensity-Duration-Frequency curves (IDF), *"Chicago Design Storms"* (CDS), which are derived from IDF-curves or other kind of design storms. These design storms allows for an intuitive understanding of the relation between the average rainfall intensity, over a specified duration, and the return period of the storm. Using these types of design storms, and point measured rainfall time series, do neglect both the spatial and temporal dynamics, which are driving factors in rainfall runoff response.

Lack of information about the spatial variability in rainfall fields are considered one of the greatest sources of errors in hydrological and hydrodynamic modelling (Thorndahl et. al, 2017). To include the spatial factor "Areal Reductions Factors" (ARF) have been introduced; a relation between peak intensity of a rainfall event and total area coverage at peak. These factors can be derived directly from a network of rain gauges or from radar data. While these, just like the IDF relations, enable an intuitive understanding of the spatio-temporal dynamics of rainfall ARF's are only applicable for design storms and not useable for temporally dynamic rainfall. A stochastic framework, known as "Stochastic Storm Transposition" (SST) has shown promising results using radar rainfall data to derive IDF-curves from a relative short period of observation.

In this study we apply the SST procedure to a high-resolution radar rainfall dataset and compare the IDF estimates with ones derived from a long record of rainfall gauges. Furthermore, the spatial structure of the areal rain is examined to enable an understanding of the relation between storm duration, return level and spatial variability.

2 Data

Radar data

This study uses a 14-year (2002-2016) 10-min 500x500m radar-estimated rainfall dataset, from a single weather radar, located 50km south of the city of Copenhagen. The dataset is bias corrected using daily mean field bias using nearby rain gauges (Thorndahl et al. 2014) to increase the quality of the precipitation product. Detailed information about technical specification and post/pre-processing of the dataset is presented in Thorndahl et al. (2017).

Regional Model

The regional model is an extreme value analysis of the Water Pollution Committee (WPC) network of rain gauges. This model will be used as validation for the SST procedure. This model is based on the WPC, (2014) recommendations.

Study Area

The study area will be focused on the Danish island Zealand and the Copenhagen area have been picked out as area of interest, as presented on figure 2.

3 Method

Stochastic Storm Transposition

A general limitation when performing frequency analysis on any timeseries data is the observation period. SST works in a stochastic framework where the radar dataset is virtually extended by re-sampling storm events not only in time but also in space. A principal sketch of the procedure is presented on figure 1.

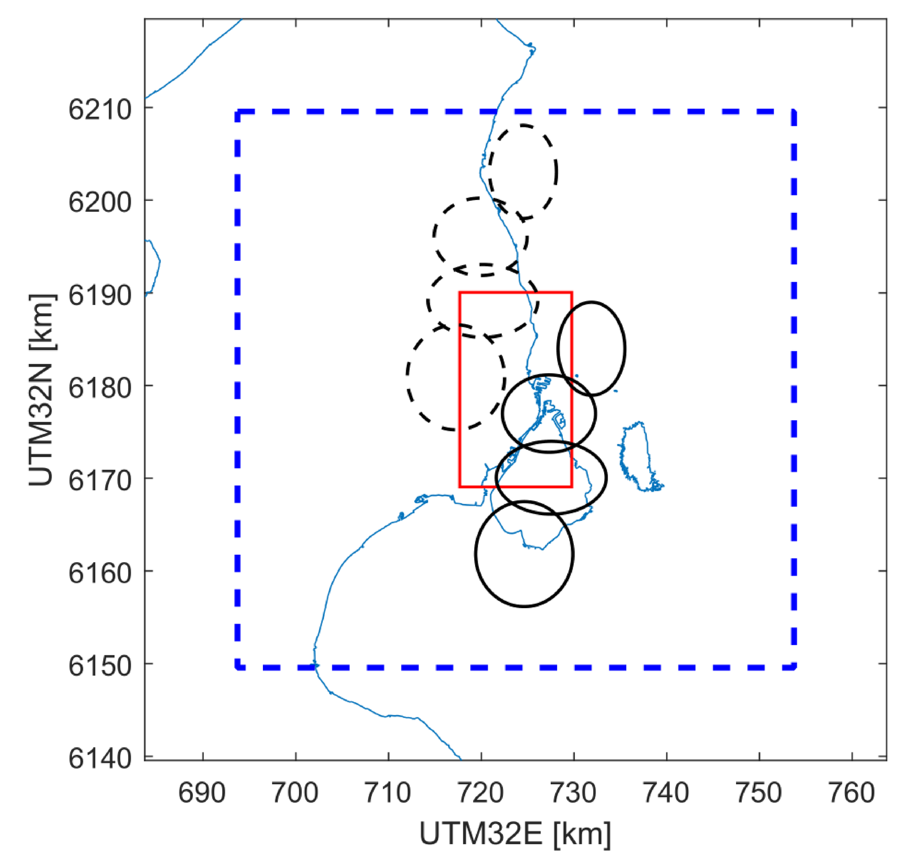

Figure #1: *Principal sketch of SST procedure. Black circles indicate original storm motion, dashed circle transposed storm. Blue dashed line indicate transposition domain and red box indicates area of interest*

By identifying a climatological homogeneous spatial domain (also known as transposition domain) it can be assumed that any storm would have equal likelihood occurring anywhere on the identified domain. The selected transposition domain can be viewed on figure 2. Homogeneity was assed through several parameters such as: Annual average rainfall, cloud to ground lightning strikes, days above 20mm. From the SST procedure rainfall events at point level will be generated and compared with the regional model. Areal storms will be generated to investigate the spatial structure of the storms through a max/mean analysis of the radar pixels and a semi-variance analysis with the range parameter as result.

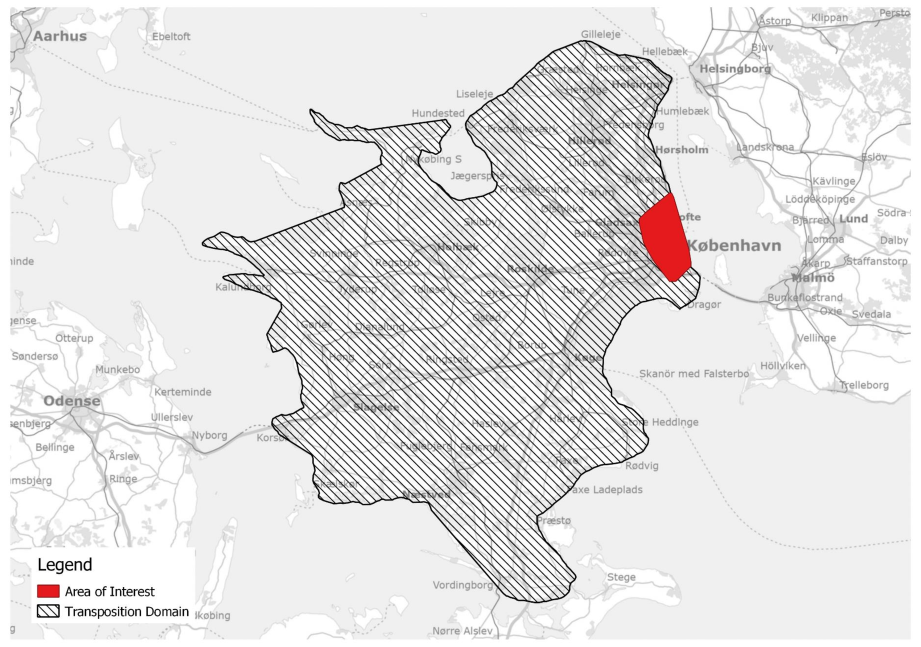

Figure #2: *Selected transposition domain for the study and area of interest.*

4 Results

IDF recreation

Figure 3 displays the SST procedure ability to recreate long-term extreme rainfall statistics. In general, the SST procedure slightly underestimates in relation to the Danish regional model. This can be explained by sub-pixel variability from radar to rain gauge. The recreated IDF's falls within the range of uncertainty of the regional model at all durations validating the method.

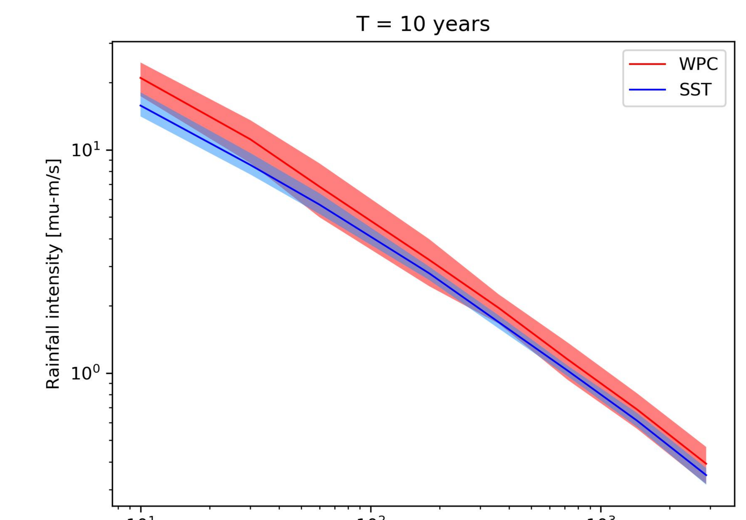

Figure #3: *The danish regional model compared to IDF estimates from SST. Shaded area indicates 95% spread. WPC are IDF-curves extracted from the regional model. T indicates return level.*

Max-mean analysis

The max-mean analysis relates the largest pixel value (R_max) in the areal storms, generated with the SST approach, with the mean value of the areal storm (R_mean). Large values indicates high spatial variability and values close to 1 indicates uniformity.

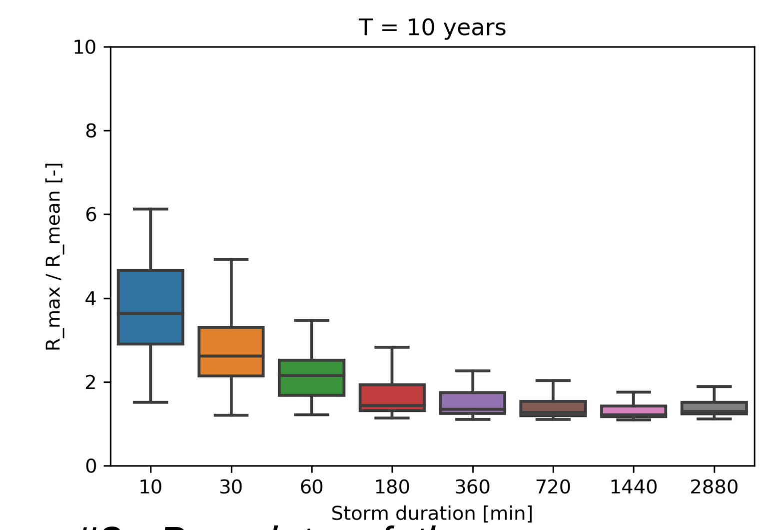

Figure #3: *Box-plots of the max-mean analysis. Median values are indicated by lines through the boxes. The edges of the box indicates 25% to 75% percentile and whiskers shows max values.*

Semi-variogram analysis

By fitting a semi-variogram model to the areal rainfall storms it is possible to examine the relation between storm duration, return period and the range parameter. The range parameter indicates the spatial limit of autocorrelation. A low value will indicate weak autocorrelation in the storm which can be interpreted as high variability. This analysis is limited to the total extent of the area of interest which means that the range parameter at maximum can show a value of ~20km which indicates strong autocorrelation and therefore can be interpreted as a uniform rainfall field. The results are presented on figure 4.

5 Results

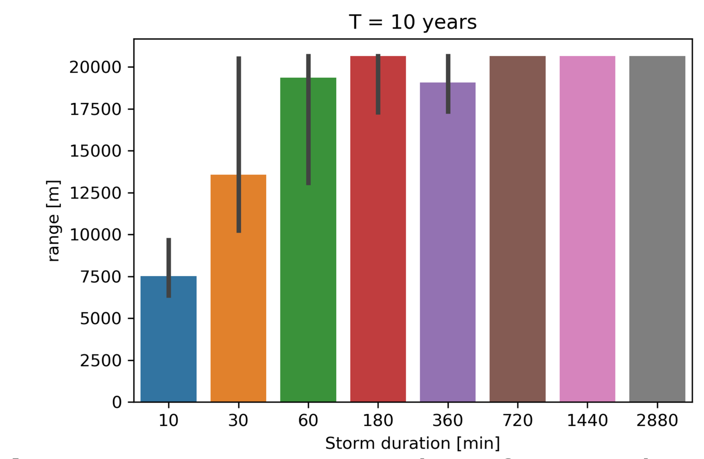

Figure #4: *Range value for each of the storm durations. Black bars indicate uncertainty interval of 95 percentile.*

6 Conclusions

The aim of this study was to review the validity of the SST procedure on data from a single, non-continuous, C-band radar dataset. The procedure in general underestimates in relation to the regional model derived from rain gauge data. This difference is often seen when comparing rain gauge data with radar data and thus the difference is considered insignificant since the results falls within the uncertainty band of the regional model.

The spatial structure of the SST generated storms was examined to form an understanding for how large an ensemble is needed to include all uncertainty in urban drainage modelling. The first measure was a simple analysis of the relation between largest pixel in the generated storm versus the mean of the storm field. This revealed that the variability is higher at the shorter duration storms. To further investigate this a semi-variogram analysis was performed on the generated storms which relies on the range parameter of the variogram that depicts the spatial limit of autocorrelation. This analysis further concluded that storms of short duration in general have a more chaotic and less organized rainfall field than those with longer durations.

Looking at the results of max-mean analysis and the semi-variogram with urban drainage design, and modelling time, in mind one could infer that a large ensemble would be needed for the short duration storms to include all uncertainties.

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